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The Heat Exchanger Performance of Shell and Multi Tube Helical Coil as a Heater through the Utilization of a Diesel Machine's Exhaust Gas

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Abstract – A review on reutilization of heat waste from a diesel machine is absolutely important. This is because the exhaust gas potential of a Diesel machine keeps increasing and not much has been utilized by the industry. One of the techniques of reutilizing the heat waste in industry is by using a heat exchanger. The technique is also very useful for the environment because it can reduce air pollution caused by the exhaust gas of the diesel machine. The main purpose of the research is to find out the capability of shell and multi tube helical coil HE as an air heater by utilizing the exhaust gas of the Diesel machine. The heat exchanger of shell and multi tube helical coil utilizes the exhaust thermal gas of the Diesel machine as the air heater already made. The apparatus has the following dimension: the shell length of 1.05 m, diameter 0.1524 m, tube length of 3.25 m with 20 coils, tube diameter of 0.011 m, coil diameter of 0.0508 m with 4 helical coils. The type of Diesel machine to use in the testing is 4FB1 Isuzu Diesel engine. The machine has the maximum machine power and rotation of 54 kW and 3,600 rpm. The performance testing of heat exchanger has been conducted in some variations of Diesel machine rotations of 1,500 rpm, 1,750 rpm, 2,000 rpm, 2,250 rpm and 2,500 rpm. The testing result shows a maximum effectiveness to happen at the machine rotation of 1,500 rpm. The maximum effectiveness to get is 67.8% and then it goes down drastically in accordance with the increase of air mass flow rate. The hot air temperature created is from 47.1°C to 52.3°C so that it can be used for the purpose of drying up the unhulled rice.

Keywords: Heat exchanger; Exhaust gas; Diesel machine; Shell; Multi tube helical coil.

Introduction

The exhaust gas from an internal combustion in fact still contains the heat energy potential which can be utilized as a heater medium. The heat reutilization of exhaust gas will have an advantage of decreasing the cost at the heating process and lowering the temperature of exhaust gas so as to decrease the environmental pollution. The efficiency of overall machine can also be increased when the heat waste can be transfered into an energy which can be utilized (Dubey *et.al*, 2015). The lost heat energy of an internal combustion machine into an environment in a form of exhaust gas is around 30-40%, depending on the machine load (Jadhao *et al.*, 2013; Nadaf *et al.*, 2014; Dubey *et al.*, 2015). In the meantime, the lost heat energy of a Diesel machine has the temperature of around 320°C to 400°C (Bouazzaoui *et.al.*, 2008). The lost heat energy is very potential especially that of a Diesel machine when utilized especially for the air and water heating technique using a heat exchanger. The heat waste utilization using a heat exchanger will be very useful to save the oil usage especially when the oil price increases. This benefit will be very much useful for the industry which needs product heating in the production process such as the industry of processing the unhulled rice into rice.

Such a process to change the unhulled rice into rice needs an adequate drying process. Drying up is a very important and critial post harvest handling in improving the rice production and quality. It is conducted to reduce the water content of unhulled rice of 13-14% for a long storage (Herawati, 2011; Graciafernandy *et al.*, 2012). Such a drying up process is troublesome when the rainy season comes because there are many society's unhulled rice processing plants which only depend on a common drying-up (natural drying-up) by using sun light in the process of drying the unhulled rice. Reducing the water content of unhulled rice can also be conducted by made-up drying of using air heating technology. There are already many kinds of air heating technology available in the market right now but the problem lies in the increasing production cost paid by the plant. The increase in production cost is due to its apparatus which uses another source of energy to heat the air so that it is inefficient and uneconomical. The survey result which the writers conduct in the society's plants of processing unhulled rice into rice shows that the people use a Diesel machine as the power source. The heat energy wasted from the Diesel machine in the plant is very potential when utilized especially for the air heating technique using a heat exchanger (HE).

Many kinds of research on the ability of various types of HE by utilizing the exhaust gas for air or water heater have been reviewed by the researchers. Zainuddin *et.al.* (2005) has conducted a research on HE effectiveness of shell and tube by utilizing the exhaust gas of a Diesel machine to heat the water and the research result shows that the highest effectiveness is at ε = 81.75%, at the load of 30 kW and the machine rotation of 2,000 rpm. The HE effectivenss of shell and tube used for an oil chiller turbin in the oil palm plant has also been analized. The result shows that the highest effectiveness is at ε = 82.19% in the innitial condition before tube-side contamination. If the contamination of heating side is varied into 10%, 20%, dan 30% then the consecutive effectiveness values are 78.39%, 73.67%; and 67.72% (Zainuddin, 2010). The HE performance of finned helical double pipe utilizing the exhaust gas of Diesel machine to heat the air as the unhulled rice dryer has also been reviewed. The research result shows that the highest effectiveness is at ε = 53.15% with the exhaust gas temperature of 440.2°C and it produces the heat air temperature of 42.1°C (Zainuddin, 2011). The HE effectiveness of a double pipe finned helical as water heater by utilizing the exhaust gas of motorcycle has also been reviewed. The testing result shows that the apparatus effectiveness is at 87% with the maximum water temperature of 97°C (Zainuddin *et.al.*, 2012). The review on HE effectiveness of a finned helical double pipe which utilizes the exhaust gas of Diesel machine as water heater has been conducted and shown ε = 65% (Zainuddin *et al.*, 2013). The experimental study of heat exchange coefficient at HE of shell and tube and the research result show that the biggest effect at the axial temperature distribution of HE is the ratio of mass flow rate. The effectiveness after modification also decreases by the increase of the ratio of mass flow rate (Al-Jabair *et al.*, 2013).

Drying is a vital operation unit in the field of agricultural products or processed materials of agricultural products storage. The most common drying-up is by directly drying it in the sun light. This is the cheapest, easiest, and oldest method. However this system has many disadvantages, when operated in a large scale, especially the hygiene problem, the necessary space, and the dependence on sun light. That is why many mechanical drier apparatus are made nowadays.

Unhulled rice drying with a convection oven has been conducted and it is concluded that the use of air drier with high temperature will increase the drying rate. The increase of drying rate is inversely proportional with the Moisture Equilibrium (Me) of the material; for 50°C drying air temperature the RH = 26% and the Me = 6.96% are obtained. For 60°C drying air temperature, the RH = 17% and the Me = 4.60% are obtained (Prasetyo *et al.*, 2008). The unhulled rice drying apparatus using air heater from husk furnace is built and tested. The test produces a good result and it is effective to be used for drying agricultural or plantation products especially for unhulled rice drying. The temperature measurement result in the drying room ranges from 40°C to 55°C where this temperature is approaching the maximum temperature of drying by the sun light (Manggala, 2008). The mechanical unhulled rice drying process using absorption drying system of zeolyte 3A in a fluidized bed dryer is examined at a low temperature and in a short time. The shortest drying time occurs at 60:40 (zeolyte:unhulled rice) composition and 60°C air temperature (Graciafernandy *et al.*, 2012). The unhulled rice drying process with a pneumatic conveyor recirculation system type is conducted and the result is that the most effective drying air temperature is 60°C and 20 m/s rate of pneumatic air flow (Gunawan e*t al.*, 2013). Therefore, the previous reports recommended that the unhulled rice drying is from 40°C to 60°C.

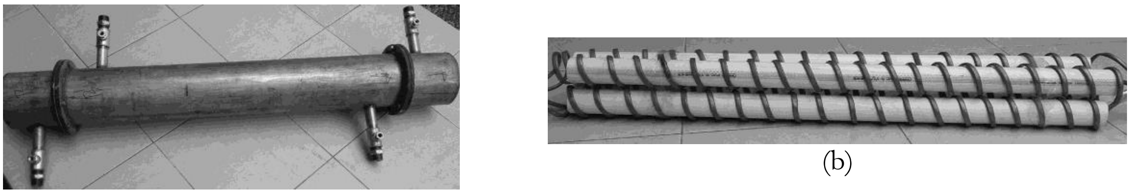
Based on the previous background and researches then the writers are interested in conducting an experimental research on the reutilization of heat waste of a Diesel machine using HE of shell and multi tube helical coil. The choice of such HE is because according to the reference it has better effectiveness compared to other types of air heating. The main purpose of the research is to find out the capability of HE of multi tube helical coil as an air heater by utilizing the exhaust gas of a Diesel machine with some variations of machine rotation. The heat air produced will be used for drying up the unhulled rice. The research result is expected to be useful especially for the government as the basic consideration of making policies in the utilization of heat waste of the Diesel machine exhaust as the alternative energy source which is quite reliable in the future.

Materials and Methods

This research implementation method starts from a preparation stage, apparatus engineering, testing, and finishing that require 10 months from February to November 2015. The preparation stage consists of literature study, survey, and apparatus designing. The apparatus engineering stage consists of HE apparatus making (shell and tube part), framework construction, pipe installation, additional apparatus procurement, and instrumentation. Next step is the testing stage which consists of research apparatus setup with instrumentation, apparatus testing and data collection. In the meantime, the last stage has been conducted.

HE of shell and multi tube helical coil

The main apparatus that are used in this research are HE of shell and multi tube helical coil type and pipe installation. HE of shell and multi tube helical coil consists of some metal pipes shaped into helical coil. The air flows inside the pipe, while the heat gas flows outside the helical coil pipe. What is so special about this type is its ability to operate under a high pressure and because there is no joint then the risk of mixing up the two fluids becomes very little. Figure 1 shows the main components of HE of shell and multi tube helical coil.



(b)

(a)

Figure 1. HE Main components; (a) Shell, (b) tube helical coil

In the meantime, the additional apparatus used are Diesel machine and blower. Diesel machine is used as an exhaust gas producer, with 1,471 cc machine capacity. The machine's maximum power and rotation are 3,600 rpm and 54 kW (72,386 hp). The blower in this research is used to absorb and push the air in the helical tube helical coil part of HE. The shape and specification of HE of shell and multi tube helical coil apparatus made and tested in this research are displayed on Figure 2. and Table 1. To support data collection stage, some measurement devices needed in the measurement to be conducted are used. The measurement devices include Lutron TM-946 digital thermometer with data acquisition software and type K thermocouple, pressure gauge, manometer, air flowmeter, and tachometer.

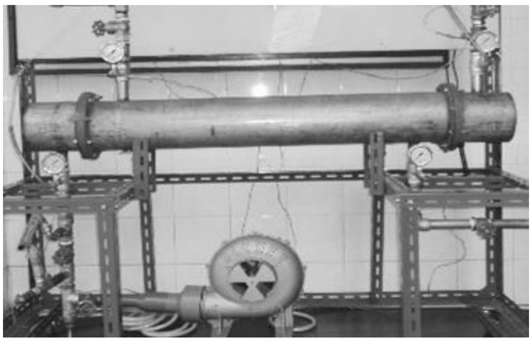


Figure 2. HE used in the research

Tabel 1. Parameter and dimension of tube helical coil

Parameter	Dimension
Shell diameter	0.1524 m
Coil diameter	0.011 m
Distance between coil	0.03 m
Tube coil width	0.001 m
Coil diameter	0.0504 m
Helical coil amount	4 pieces
HE length	1.046 m
Helical coil material (Copper)	396 W/m.°C

Experimental setup

Before data collection stage begins, it must be assured that the research apparatus are ready to be used. This stage starts by setting up the research apparatus with instrumentation. In this research, that stage is displayed in Figure 3. Meanwhile the variables measured and the measurement devices used in the research are displayed in Table 2.

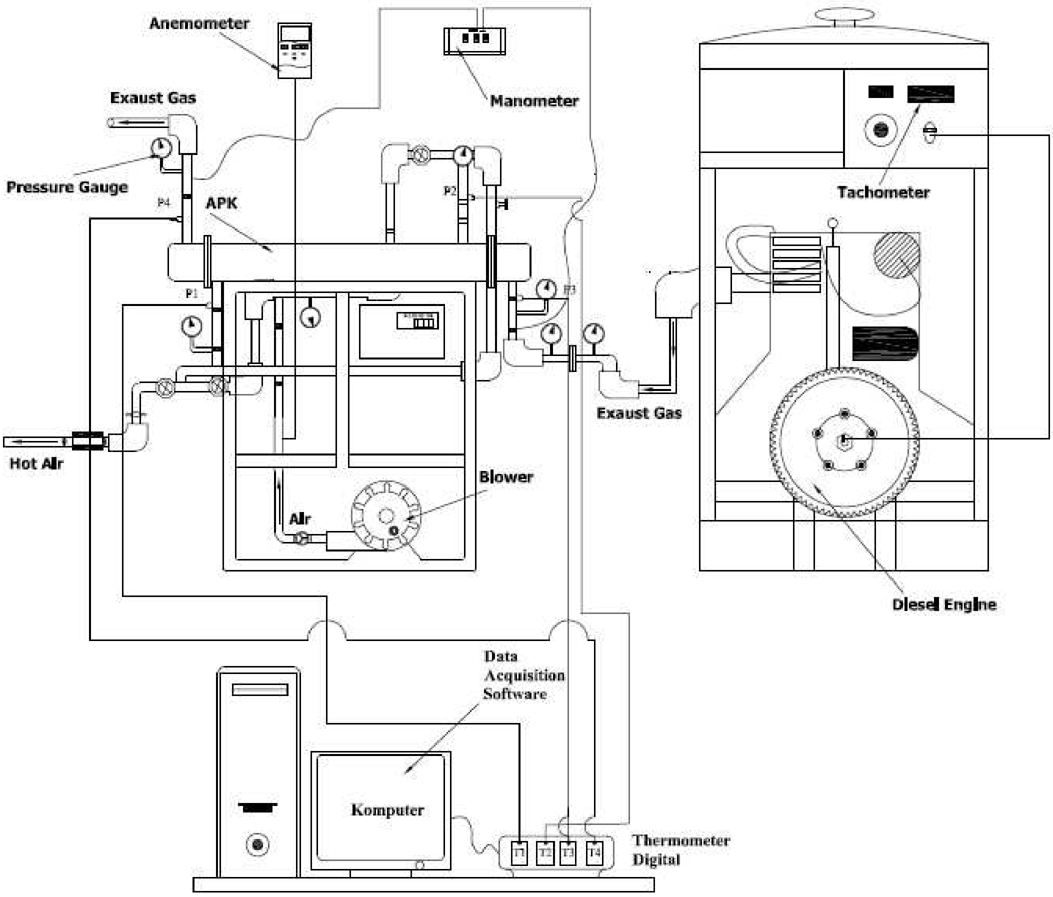


Figure 3. Apparatus for heat exchanger experiment

Table 2. Measured variables and used measurement devices in the research

Measured variables	Descriptors	Instrumentation
Initial temperature of air ($T_{c,i}$)	°C	Digital thermometer and thermocouple
Outlet temperature of air ($T_{c,o}$)	°C	Digital thermometer and thermocouple
Initial temperature of exhaust gas ($T_{h,i}$)	°C	Digital thermometer and thermocouple
Outlet temperature of exhaust gas ($T_{h,o}$)	°C	Digital thermometer and thermocouple
Initial pressure of air ($p_{c,i}$)	Pa	Pressure gauge and Manometer
Outlet pressure of air ($p_{c,o}$)	Pa	Pressure gauge and Manometer
Initial pressure of exhaust gas ($p_{h,i}$)	Pa	Pressure gauge and Manometer
Outlet pressure of exhaust gas ($p_{h,o}$)	Pa	Pressure gauge and Manometer
Rate of air flow ($\dot{m}_c$)	kg/s	Air flowmeter
Machine rotation	rpm	Tachometer

Result and Discussion

HE shell and tube capability can be identified from some parameters which are f (coefficient of friction), Re,c (Reynolds number on the tube helical coil side), Δp (pressure drop), De (Dean number), NTU (number of thermal units), $T_{,co}$ (hot air temperature on tube helical coil side), $\dot{m}_c$ (hot air mass flow that flows inside the tube helical coil) and ε (HE effectiveness). According to Hewitt (1994) the amount of heat absorbed by cold fluid, Q_c (kW) is directly proportional with the multiplication of rate of water mass flow, $\dot{m}_c$ with air specific heat, $c_{p,c}$ as well as the difference of going-out air temperature, $T_{c,o}$ and in $T_{c,i}$. It can be written down mathematically as in the equation (1).

$$Q_c = \dot{m}_c \times c_{p,c} \times (T_{c,o} - T_{c,i}) \quad (1)$$

Meanwhile the amount of heat released by the hot fluid is a modification from the equation (2).

$$Q_h = \dot{m}_h \times c_{p,h} \times (T_{h,i} - T_{h,o}) \quad (2)$$

Where Q_h is heat that is released by hot fluid and $\dot{m}_h$ is the rate of exhaust gas mass flow and $c_{p,h}$ is exhaust gas specific heat. $T_{h,o}$ and $T_{h,i}$ is the difference between coming-in and going-out exhaust gas temperature.

The characteristics of cold and hot fluid are evaluated on an average temperature using the equation (3).

$$T = \frac{T_i + T_0}{2} \quad (3)$$

To calculate the rate of mass flow from the two fluids heat energy equilibrium relation is used like in the equation (4).

$$\dot{m}_h = \frac{\dot{m}_c \, . c_{p,c} . (T_{c,o} - T_{c,i})}{c_{p,h} . (T_{h,i} - T_{h,o})} \quad (4)$$

Exhaust gas from a Diesel machine is usually used as a heating medium to heat other media so that heat transfer occurs whether through conduction or convection. There are many types of heat transfer apparatus that can be used to utilize heat from a Diesel machine exhaust gas but the problem lies in the heat absorbing capability (effectiveness) from those apparatus. To determine the effectiveness according to Hewitt (1994), the minimum heat capacity from cold and heat fluids must be determined. To determine heat capacity value for cold fluid (C_c), the equation (5) is used.

$$C_c = \dot{m}_c \times c_{p,c} \quad (5)$$

Where $\dot{m}_c$ is rate of air mass flow (kg/s) and $C_{p,c}$ is air specific heat (J/kg.K).

Meanwhile to determine the heat capacity value for hot fluid (C_h), the equation (6) is used.

$$C_h = \dot{m}_h \times c_{p,h} \quad (6)$$

If cold fluid is the minimum fluid, the heat transfer apparatus effectiveness can be obtained through the equation (7).

$$\varepsilon = \frac{(T_{c,o} - T_{c,i})}{(T_{h,i} - T_{c,i})} \quad (7)$$

If hot fluid is the minimum fluid, the heat transfer apparatus effectiveness can be obtained through the equation (8).

$$\varepsilon = \frac{(T_{h,i} - T_{h,o})}{(T_{h,i} - T_{c,i})} \quad (8)$$

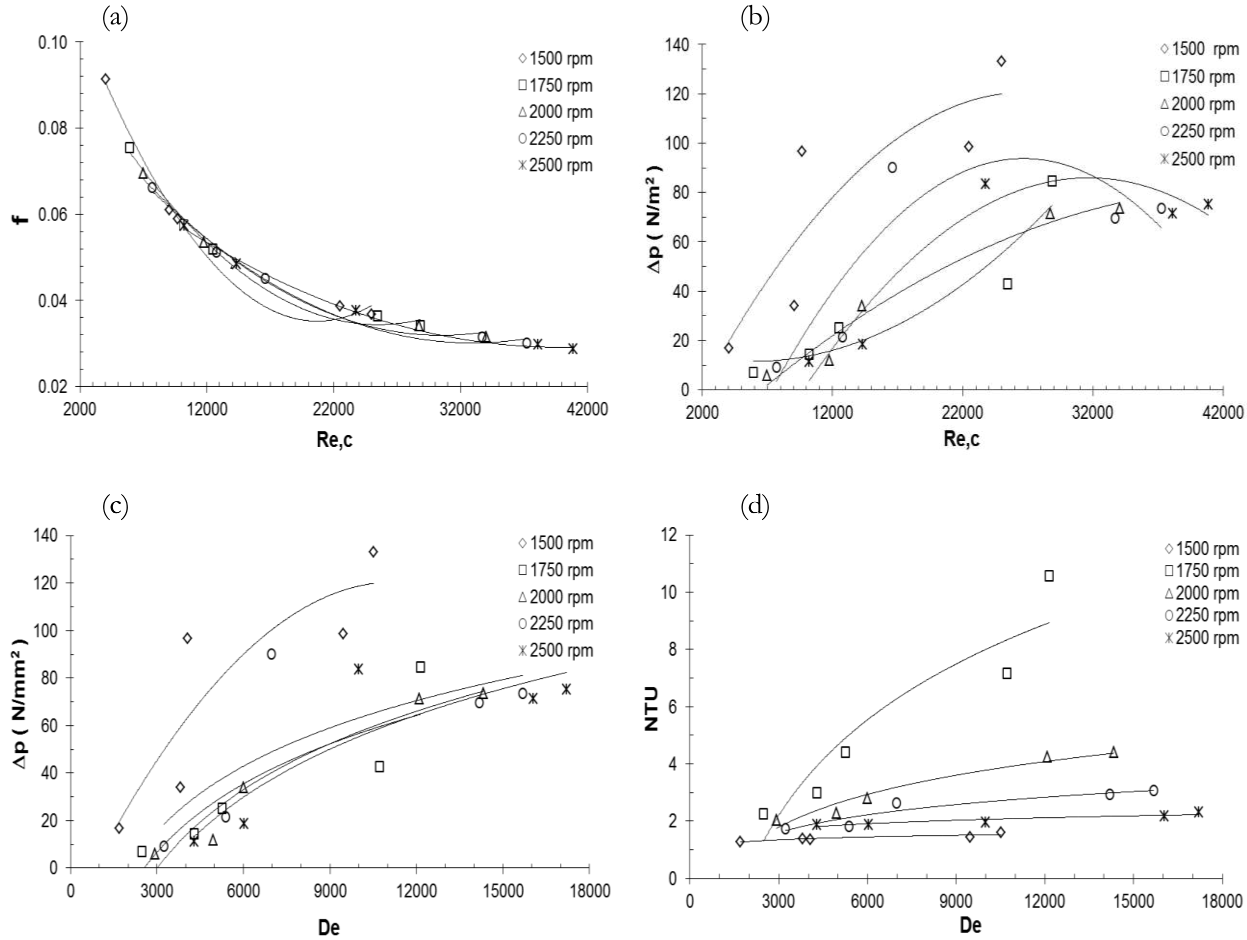


Figure 4. (a). Graphical correlation between coefficient of friction and Reynolds number (b). Graphical correlation between pressure drop and Reynolds number, (c). Graphical correlation between pressure drop and Dean number, (d). Graphical correlation between number of thermal units and Dean number.

The correlation in a graphical form of those parameters is displayed in detail in Figures 4. and 5. Figure 4 (a) shows a graphical correlation between coefficient of friction and Reynolds number on the tube helical coil side with five different variations of machine rotation. This graph shows that the coefficient of friction that occurs inside the tube helical coil is continuously decreasing along with the increase of Reynolds number for each machine rotation. The maximum coefficient of friction value occurs at the lowest rotation, which is 1,500 rpm and the minimum at the highest rotation, which is 2,500 rpm. This is because the air flows in the tube helical coil absorbing much heat from outside the tube helical coil at 1,500 rpm rotation and a little at 2,500 rpm rotation. Figure 4(b) shows a graphical correlation between pressure drop and Reynolds number in five different variations of machine rotation. The maximum pressure drop in tube helical coil part occurs at the lowest machine rotation, which is 1,500 rpm and the minimum value occurs at the highest machine rotation, which is 2,500 rpm. This is becaue the fluid (air) friction with the surface inside of the tube helical coil is very high at the lowest machine rotation, while it is found to be less at the highest machine rotation.

Figure 4(c) shows a graphical correlation between pressure drop and Dean number in five different variations of machine rotation. It can be observed from this graph that the maximum pressure drop occurs at the lowest machine rotation, which is 1,500 rpm and the minimum occurs at the highest rotation, which is 2,500 rpm. Afterwards, the pressure drop increases along with the increase of Dean number. This is due to the increase of Reynold number value on the inside of tube helical coil. In addition Figure 4(d) shows a graphical correlation between the number of thermal units and Dean number on five different variations of machine rotation. It can be observed from this graph that the maximum thermal unit number occurs at 1,750 rpm machine rotation. Meanwhile, the maximum thermal unit number occurs at the lowest rotation, which is 1,500 rpm and increases along with the increase of Dean number.

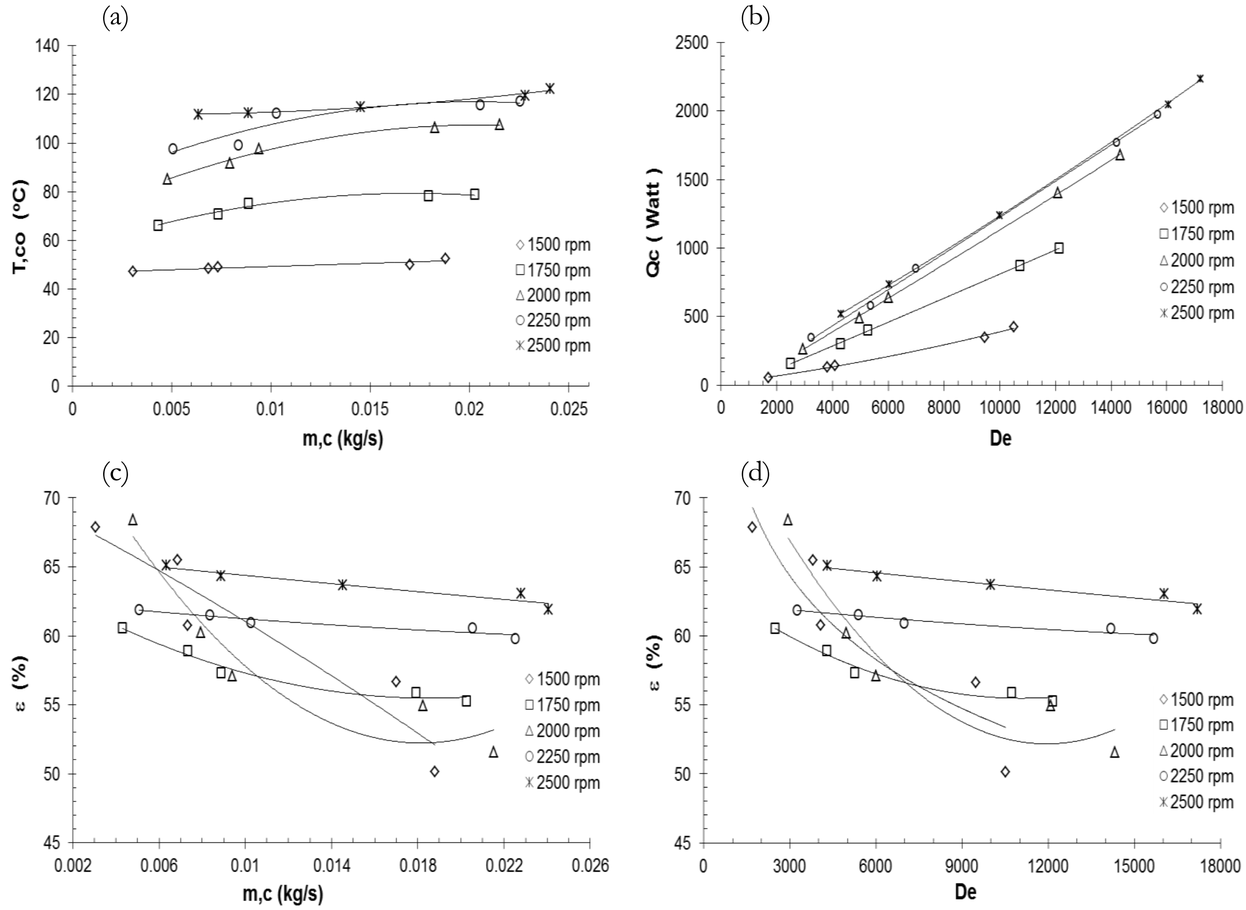


Figure 5. (a). Graphical correlation between hot air temperature coming out from tube helical coil and the flow of hot air mass that flows inside the tube helical coil, (b). Graphical correlation between absorbed heat and Dean number, (c). Graphical correlation between effectiveness and the rate of air mass flow, (d). Graphical correlation between effectiveness and Dean number.

Figure 5(a) shows a graphical correlation between the temperature of hot air that comes out from the inside of tube helical coil and the rate of hot air mass flow that flows from helical from tube helical coil in five different variations of machine rotation. It can be observed from this graph that the maximum air temperature is 122.4°C, which is obtained at the highest machine rotation, which is 2,500 rpm. The minimum air temperature is 47.1°C and maximum 52.3°C, which is obtained at the lowest machine rotation, which is 1,500 rpm. This shows that the hot air can only be used at the minimum machine rotation, which is 1,500 rpm to dry the unhulled rice. This is due to the allowed unhulled rice milling temperature which is about 40°C to 60°C. Meanwhile, if the drying is conducted above that temperature, the unhulled rice will be damaged and the rice quality will decrease. Figure 5. (b) shows a graphical correlation between absorbed heat and Dean number in five different variations of machine rotation. It can be observed from the graph that the maximum absorbed heat by the helical coil part from HE occurs at the highest machine rotation, which is 2,500 rpm. Meanwhile, the minimum absorbed heat by tube helical coil occurs at the lowest rotation, which is 1,500 rpm. This is because at 2,500 rpm machine rotation, the rate of hot air mass flow and the exhaust gas temperature obtained are high enough compared to the other four machine rotations. Figure 5. (c) shows a graphical correlation between effectiveness and rate of air flow mass coming out from the tube helical coil in five different variations of machine rotation. It can be observed from this graph that the maximum effectiveness occurs at 1,500 rpm machine rotation with 0.003 kg/s rate of air mass flow. The exhaust gas temperature in this condition is 63.7°C with 0.0134 kg/s rate of mass flow. The highest effectiveness from HE in this rotation is 67.8% and afterwards it decreases drastically along with the rate of air mass flow. The hot air temperature that is produced at 1,500 rpm rotation is 47.1°C to 52.3°C which can be used for the unhulled rice drier needs because it is still within the temperature limit allowed, which is from 40°C to 60°C.

Figure 5(d) shows a graphical correlation between effectiveness and Dean number in five different variations of machine rotation. The graph generally shows that the higher the Dean Number gets, the lower the HE effectiveness on each of the machine rotation is. The maximum effectiveness is obtained at 1,500 rpm machine, which is 67.8%. This effectiveness is obtained at 1698.072 Dean number value and 63.7°C exhaust gas temperature. Meanwhile, the hot air temperature produced at 1,500 rpm rotation from 47.1°C to 52.3°C can be used for the unhulled rice drier needs.

Conclusions

Testing the ability of the HE type multi tube helical coil by utilizing Diesel engine exhaust very well be applied to heating the air as performed relatively well. The maximum HE effectiveness with four variations of machine rotation is 67.8%. This is obtained at 1,500 rpm machine rotation ranging from 47.1°C to 52.3°C which can be used for the unhulled rice drier needs. This is because of a reference that allows the unhulled rice drying temperature in the range of 40°C to 60°C. It is recommended that the exhaust gas be produced for every Diesel machine rotation so that it is necessary to create a temperature control system. This system functions to keep the temperature constant inside the drier room and can be adjusted to the drying needs.

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